



Consistency between Sweat Rate and Wet Bulb Globe Temperature for the Assessment of Heat Stress of People Working Outdoor in Arid and Semi-arid Regions

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Abstract

Background: Heat stress is common among workers in arid and semi-arid areas. In order to take every preventive measure to protect exposed workers against heat-related disorders, it is crucial to choose an appropriate index that accurately relates environmental parameters to physiological responses.

Objective: To investigate the consistency between 2 heat stress and strain indices, *ie*, sweat rate and wet bulb globe temperature (WBGT), for the assessment of heat stress of people working outdoor in arid and semi-arid regions in Iran.

Methods: During spring and summer, 136 randomly selected outdoor workers were enrolled in this study. Using a defined protocol, the sweat rate of these workers was measured 3 times a day. Simultaneously, the environmental parameters including WBGT index were recorded for each working station.

Results: The level of agreement between sweat rate and WBGT was poor ($\kappa < 0.2$). Based on sweat rate, no case exceeding the reference value was observed during the study. WBGT overestimated the heat stress in outdoor workers compared to sweat rate.

Conclusion: It seems that the sweat rate standards may need some modifications related to real condition of work in arid and semi-arid regions in Iran. Moreover, it seems that judging workers solely based on monitoring their sweat rate in such regions, can probably result in underestimation of heat stress.

Keywords: Sweat; Climate; Heat stress disorders; Hot temperature; Humidity

Introduction

Heat stress, which includes a series of conditions where the body is under stress from overheating,

can be a major problem for many types of people including the elderly, newborns and children, pregnant women, and outdoor workers. It can cause many illnesses ranging from simple fatigue, lethargy, and



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weakness to serious conditions such as heat stroke or heat syncope.¹ Many workers must work outdoor.^{1,2} They spend more than one-third of every day outdoor, being exposed to varying degrees of heat stress.^{3,4} Monitoring occupational health hazards and protection of workers from them are among important missions of occupational hygienist. However, the hygienist needs reliable and applicable tools, methods, and equipment to accurately measure these hazards.

There are several heat stress and strain indices for monitoring and evaluation of thermal condition in different climates.⁵⁻⁷ Some of them, such as wet bulb globe temperature (WBGT), have been validated and used as a popular index worldwide.⁷⁻⁸ However, in spite of wide usage and applicability of WBGT, it is associated with some limitations making it only a screening tool for thermal conditions. For example, the efficiency of WBGT is limited in very hot and humid conditions.⁹ Therefore, a more detailed analysis through accurate rational indices such as predicted heat strain (PHS) or heat-related physiological responses is strongly recommended whenever a primary heat stress condition is dealt with.¹⁰

The core temperature, especially rectal temperature, as well as sweat rate are two parameters that create the best correlation with changes in environmental thermal

condition.^{10,11} Nevertheless, their applicability and adoption were restricted in real field studies due to the very sophisticated and difficult measurement methods to be used (in the case of sweat rate) and also ethical and cultural issues (in the case of rectal temperature).¹² Because of the priority of heat-related physiological responses and reliance of indices on thermal equilibrium equation of human body on one hand, and limitations of empirical indices including their dependency on climate, community, and condition, on the other hand, we conducted this study to answer the following two questions: Considering some difficulties in the measurement of the sweat rate, is it wise to solely rely on this index for evaluation of thermal condition in different climates? And, how is the level of agreement between the sweat rate and WBGT (a valid and popular heat stress index) in environmental conditions with different ambient humidity and temperature?

Materials and Methods

Participants

We randomly selected 136 healthy outdoor male workers from five climates. A two-stage sampling protocol was used. First, based on the annual precipitation, studied regions were categorized into two categories of “arid,” areas with an average annual precipitation of 100–250 mm, and “semi-arid,” areas with an average annual rainfall of 250–450 mm.¹³ Considering each province a cluster, proportional cluster random sampling was used. Based on the number of clusters (provinces in the country for each category), 79 workers from arid areas and 57 from semi-arid regions were randomly selected. The participants aged between 18 and 62 years; all had at least one year of job experience in the region, and were thus assumed to have been acclima-

TAKE-HOME MESSAGE

- Heat stress is a major harmful physical condition for outdoor workers.
- Sweat rate monitoring is one of the best heat strain index for thermal monitoring.
- Monitoring sweat rate in hot climates alone can probably cause underestimation of the situation.
- The results obtained from sweat rate and wet bulb globe temperature have a poor level of agreement.

tized. Workers with any disorders or history of illnesses such as hypertension, renal, cardiovascular and skin disorders, and those with any conditions causing excess sweating were excluded from the study. Demographic characteristics of the studied workers were collected using a tailor-made questionnaire. To assess the level of agreement between sweat rate and WBGT, we performed the tests twice in spring and summer in five regions.

Personal and Environmental Parameters

Thermal insulation of workers' clothes and the level of work load were estimated according to ISO 9920 (2004) and ISO 8996 (1989), respectively.^{14,15} An advanced calibrated heat stress monitor (Casella Microtherm WBGT, UK) was used for recording dry air temperature (t_a), natural wet temperature (t_{nw}), globe temperature (t_g), and WBGT index. A digital manometer (Lotron PHB 318, Taiwan) was used for measuring relative humidity. Air velocity was measured with a thermal anemometer (Kimo, Franch). To consider the effect of worn clothes by the workers on WBGT, effective WBGT, which is the environmental WBGT plus clothes adjustment factor (CAF), was estimated.¹⁴ All parameters were recorded three times in a 4-hour interval from 8:00 to 12:00 am. The mean of each measurement made between 8:00 and 10:00 am and 10:00 to 12:00 am was used in analysis. Considering the sample size ($n=136$), two measurements a year (spring and summer), and two measurements a day, we came to a total of 544 measurements for each parameter.

Sweat Rate Measurement

Sweat rate was calculated from weight difference before and after heat exposure adjusted for water intake and urine output. A scale (Weigh-Sanova, Iran) with an accuracy of ± 10 g at the range of 20–130 kg was used on site to weigh each worker at the

beginning and end of each time interval. The measurements were made three times a day at about 8:00, 10:00, and 12:00 am. The total sweat was determined using the following equation:

$$\text{Total Sweat} = \text{Primarily weight} - \text{Secondary weight} + \text{Drink} - \text{Urine}$$

After calculating the total sweat in the two study periods, the sweat rate was calculated. In addition to total sweat, total dehydration was computed. For this purpose, the amount of sweat rate was multiplied by the duration of exposure (2 hours in this study).

Ethics

The study protocol was approved by Ethics Committee of Tehran University of Medical Sciences, Tehran, Iran. Studied workers participated voluntarily in the study and were informed of the main objectives of the study. Informed consent was taken from the workers. The workers were allowed to withdraw from the study at any time they wish.

Statistical Analysis

SPSS® ver 20 for Windows®, was used for data analyses. *Student's t* test for independent samples, Spearman's ρ , and κ statistics were used for data analyses. A p value < 0.05 was considered statistically significant.

Results

The studied workers working in arid and semi-arid regions were similar in terms of many demographic characteristics. However, those working in semi-arid regions had a significantly higher job experience ($p=0.002$) and a lower metabolic rate ($p=0.001$) than those working in arid regions (Table 1). On the other hand, all the environmental parameters measured, but globe bulb temperature and air velocity, were significantly different in arid and

Table 1: Demographic characteristics of the workers in two arid and semi-arid regions (n=136). Values are mean (SD).

| Parameter | Arid climate (n=79) | Semi-arid climate (n=57) | p value |
|-------------------------------------|---------------------|--------------------------|---------|
| Age (yrs) | 35.6 (9.3) | 35.7 (9.4) | 0.83 |
| Job experience (yrs) | 10.6 (7.3) | 12.6 (8.0) | 0.002 |
| Metabolic rate (W) | 332.0 (50.9) | 318.7 (40.9) | 0.001 |
| Thermal insulation of clothes (clo) | 0.8 (0.2) | 0.8 (0.2) | 0.18 |
| Body area (m ²) | 1.87 (0.17) | 1.88 (0.19) | 0.36 |
| BMI (kg/m ²) | 24.7 (4.0) | 25.0 (4.5) | 0.48 |

semi-arid regions (Table 2).

The climate in Iran varies extensively in arid and semi-arid regions (Table 2). Sweat rate and dehydration level as well as the reference values for each parameter are presented in Table 3. These values correspond to an 8-hour exposure period. Considering the 2-hour duration of exposure in our study, the reference values for dehydration were equal to 1300 g. Based on the 2-hour exposure limit values for acclimatized workers for dehydration and sweat rate, sweat rate and dehydration level did not exceed the reference value during the study (Table 3). The mean effective WBGT, however, exceeded the reference value during the same period (Table 4).

Based on WBGT heat stress monitoring results, the heat stress was higher during the 10:00 to 12:00 am period (Table 4). The level of agreement between sweat rate and WBGT results was poor (Tables 5, 6).

Measuring heat stress based on sweat rate resulted in less frequent impermissible conditions than that WBGT showed (Table 5). The sweat rate in study site 5 was much higher than that in other sites (Table 6). Explaining less than 20% of variability in the sweat rate, air temperature and relative humidity in studied regions had low correlations with it (Fig 1). The change in sweat rate in our study with air temperature was not significant up to 30 °C. Thereafter, a noticeable increase in the sweat rate was observed with increasing the air temperature (Fig 1). This condition is reverse for the association between the sweat rate and the relative humidity, so that a decreasing trend could be seen for sweat production rate against relative humidity in the range of 20%–50%, followed by a nearly constant rate up to 60%, followed by a less steeper slope with further increase in the air moisture (Fig 1).

Table 2: Environmental parameters in studied arid and semi-arid regions (n=544). Values are mean (SD).

| Parameter | Arid climate (n=316) | Semi-arid climate (n=228) | p value |
|------------------------------------|----------------------|---------------------------|---------|
| Air temperature (°C) | 30.6 (6.2) | 32.1 (4.6) | 0.002 |
| Natural wet temperature (°C) | 19.7 (2.9) | 22.6 (2.6) | <0.001 |
| Globe bulb temperature (°C) | 34.8 (6.3) | 35.4 (5.2) | 0.19 |
| Relative humidity (%) | 40.5 (12.0) | 46.2 (9.2) | <0.001 |
| Water partial vapor pressure (kPa) | 1.71 (0.28) | 2.18 (0.36) | <0.001 |
| Air velocity (m/s) | 1.4 (1.0) | 1.1 (1.8) | 0.08 |

Table 3: Total dehydration and sweat rate of the studied workers. Values are mean (SD).

| Parameter | During 8:00–10:00 | During 10:00–12:00 | Reference value* |
|------------------|-------------------|--------------------|--------------------------|
| Dehydration (g) | 410.8 (282.7) | 711.7 (457.7) | 3250 [5200] [†] |
| Sweat rate (g/h) | 205.4 (141.4) | 355.9 (228.8) | 650 [1000] |

*The values in the bracket are the reference value for acclimatized persons. For acclimatized subjects, the maximum sweat rate is, on average, 25% greater than for un-acclimatized subjects.⁶

[†]The presented values are for an 8-hour exposure period; therefore, the exposure time must be considered.

Discussion

Studied workers in semi-arid regions had a significantly higher work experience than those in arid areas. One may assert that higher work experience could cause higher sweat loss through acclimatization. However, we observed a higher sweat loss in arid regions (Table 6) with lower work experience of workers. This reflects higher importance of environmental parameters compared to personal characteristics in evaluation of heat strain.

The climate in Iran varies extensively in arid and semi-arid regions. Both sweat rate and dehydration did not exceed the reference value during the study period (8:00–12:00 am), however, the mean WBGT exceeded the reference value at the same period. These values, however, may be increased, depending on the condition, if the work lasts more than 4 hours. This means that compared to sweat rate, evaluation of the heat stress using WBGT would result in an overestimation in studied regions. This is clearly apparent when we compared the results of sweat rate and WBGT: while sweat rate values were within the permissible limit during the study period, for many cases the WBGT values exceeded the acceptable limit (Table 5). We also found a poor level of agreement between the sweat rate and WBGT. Similar observations were made in several reports.^{16–18}

In a similar study, Bate, *et al*, examined the physiological responses of construction workers in the United Arab Emirates and showed that in case of the supply of

body fluids and self-pacing, workers can work in summer without serious physiological consequences.¹⁹ Wasterlund (1996) proposed that WBGT and a few other related indices should not be used for estimation of physiological strain in agriculture.²⁰ Continuous working without scheduled work-rest regimen, high radiance and lack of enough or available healthy and cool water for necessary rehydration can explain why the WBGT index is not applicable in such conditions.²⁰ Another study conducted on farmers, reveals that from three physiological responses related to heat stress including heart rate, raised body temperature, and sweating, only the heart rate approaches the threshold limit and sweat rate rarely reaches or exceeds the threshold limit value.¹⁸ On the other hand, replacing the water loss is important and strongly advised.²¹ ISO 7933 (ISO, 2004) recommends a maximum acceptable water loss by sweating of 5% of body weight in order to protect 95% of the population. This threshold came from the hypothesis that rehydration rate is 40% of the water loss in 95% of the cases.⁶

In our study, as expected, we found that there were higher sweat rates in regions

Table 4: Heat stress monitoring results based on WBGT. Values are mean (SD).

| Parameter | During 8:00–10:00 | During 10:00–12:00 |
|-------------------------|-------------------|--------------------|
| Environmental WBGT (°C) | 23.5 (3.2) | 26.2 (3.6) |
| Effective WBGT* (°C) | 24.7 (3.5) | 28.1 (4.4) |

*Environmental WBGT + Clothes adjustment factor

Table 5: Number of agreements and disagreements in classifying studied workers using sweat rate and WBGT.

| WBGT (°C)* | | Sweat rate (g/h) [†] | | κ (95% CI) |
|------------------------|--------------|-------------------------------|---------------|---------------------|
| | | Permissible | Impermissible | |
| 8:00–10:00 (n=272) | Acceptable | 269 | 3 | — |
| | Unacceptable | 0 | 0 | |
| 10:00–12:00 (n=272) | Acceptable | 170 | 10 | 0.13 (0.12 to 0.14) |
| | Unacceptable | 77 | 15 | |
| 8:00–12:00 (n=544) | Acceptable | 439 | 13 | 0.18 (0.17 to 0.19) |
| | Unacceptable | 77 | 15 | |

*The reference value for WBGT was chosen according to ACGIH, to be 28 °C, assuming moderate work, normal clothes insulation, and continuous work in an acclimatized worker.

[†]The reference value for sweat rate was chosen to be 1000 g/h, assuming all studied workers had been acclimatized.

with higher temperatures and lower humidity such as study sites 1 and 5 (Table 6). The main reason for this finding was due to the higher dry and radiant temperature than the skin temperature of 35 °C. In addition, the low observed coefficients of determination indicated that sweat rate not depends on air temperature and relative humidity, but it also depends on other environmental and personal parameters such as air velocity, and dry and wet insulation of the clothes, among other things.

The arid and semi-arid regions in Iran are usually very hot deserts with long hours of sun radiation in the center of Iran. Moisture is low in these areas; in

some parts, it is so low that the moisture level is as low as 20%–30% and the radiant temperature is about 50 °C. The combined effect of these two environmental factors plays a pivotal role in developing heat stress in these areas. Under such circumstances, conventional and radiational heat can be absorbed by human body. Therefore, these routes are not adequate for heat loss; the only way to lose excess body heat is through evaporation of sweat from the skin. Low humidity in such areas can help evaporation of sweat and heat loss from the body. McArdle, *et al*, developed the predicted 4-hour sweat rate index, which uses sweat rate as an indicator

Table 6: Mean (SD) sweat rate and correlation between WBGT and sweat rate for evaluation of thermal environments in different climates

| Study site | Nominal category* | n | Sweat rate (g/h) | Spearman's ρ^{\dagger} |
|------------|--|-----|------------------|-----------------------------|
| 1 | An arid, cool and warm to very warm region | 100 | 296.6 (247.6) | 0.28 |
| 2 | A semi-arid, moderate and very warm region | 108 | 252.4 (190.5) | 0.36 |
| 3 | A semi-arid, cool and warm region | 120 | 251.1 (160.4) | 0.24 |
| 4 | An arid, cool and warm region | 120 | 227.5 (157.0) | 0.36 |
| 5 | An arid, cool and very warm region | 96 | 399.3 (225.5) | 0.48 |

*Cool in the nominal category is one of the properties of winter weather conditions, not necessarily spring and summer weather conditions which is emphasized in this study.¹

[†]All correlation coefficients are significantly different from zero.

of heat strain and predicts sweat rate for 4 hours for different combinations of metabolic rates and climatic conditions.²² However, it was shown that sweat production by itself, does not predict the occurrence of heat strain.²³

In another study, WBGT and predicted heat strain were measured and found that although the predicted sweat rate is not different in the warm humid and hot dry environments, the evaporation rate is significantly lower in the warm humid areas. In a dry heat environment, none of the indices proposed consider the higher sweating capacities in physically-trained men.²⁴ In a previous study, the WBGT failed to differentiate between strenuous warm humid conditions and hot dry environments that did not result in excessive physiological strain.^{19,25}

The amounts of sweat rate vary for different populations. For example, Stofan, *et al*, studied 10 members of a Florida football team in a 2.5-hour practice. The average sweat loss exceeded 4 L for the players with a history of heat cramps.²⁶ Moreover, self-pacing in conditions with lack of work-rest cycles to decrease heat stress, causes physiological responses to heat, such as maintaining the sweat rate within the permissible limit, despite existence of stressful environmental conditions assessed based on WBGT.²⁷

The fact that the present study was conducted in real work settings can be considered the strength of this study; a lot of affecting parameters on sweat rate and evaporation such as environmental and personal parameters as well as emotional behavior of the studied workers were considered. However, the limitations in measuring the exact amount of the sweat produced, evaporated, and the amount of sweat left on the skin are limitations of this study.

In conclusion, it seems that the sweat rate standard level at a shift work may need

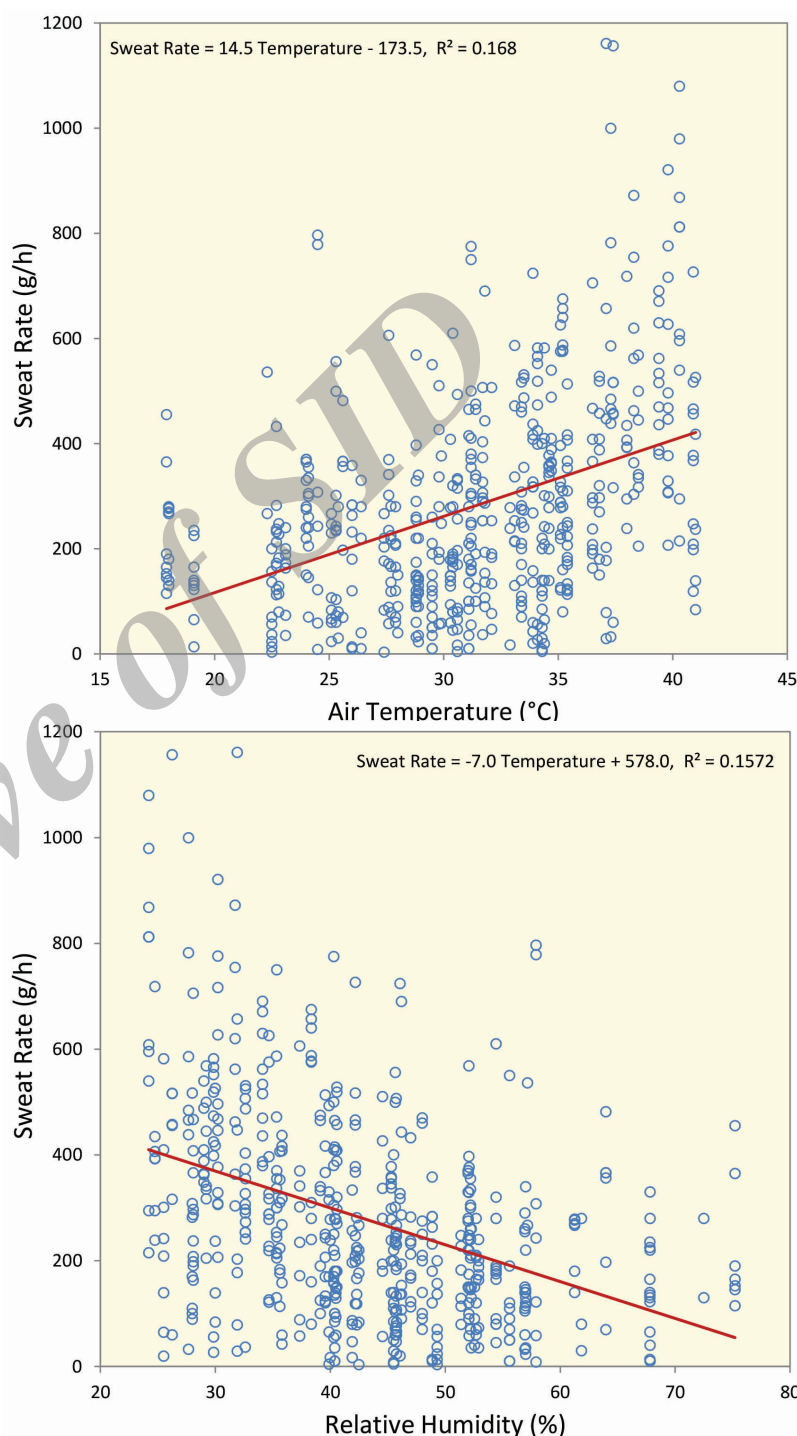


Figure 1: Sweat rate at different temperatures and relative humidity

some modifications related to real condition of work in arid and semi-arid climates of Iran and that judgment solely based on

monitoring sweat rate, as a physiological response to heat in these climates, may underestimate the situation.

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Conflicts of Interest: None declared.

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